PETROGRAPHIC EVALUATION OF COKING POTENTIAL OF SELECTED ALASKAN COALS AND BLENDS

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INTRODUCTION

The United States Bureau of Mines, Geological Survey, and other agencies have made extensive investigations on Alaskan coals. Coke tests on Alaskan coals as early as 1908 have indicated that a few coals are of coking quality. However, lack of known coking coal reserves large enough for economic exploitation precludes competitive marketing. These coals which do indicate coking quality often occur in isolated areas and in complex geologic structure, thus prohibiting development.

This study by no means defines the economic feasibility of mining, processing, or marketing of potential coking coals, but rather is concerned with new innovations of coal science to determine the possibility of blending coking coals with non-coking coals. Results indicate that coherent coke products may be made by this blending and further illustrates a possible increase in reserves of coking coal.

The changes which coal undergoes at elevated temperatures are directly influenced by the properties, percentages, and structural interrelationship of the macerals. Petrographic techniques are employed to identify macerals and determine their percentage distribution. These results are then related to coke tests to determine how the absence or presence of the macerals affects the behavior of the coal.

The optimum ratio of "reactive" to "inert" materials for each coal has been established by isolating each of the macerals and determining for each what ratios of eractives to inerts give the greatest coke strength or Petrographic examination allows the determination of composition balance and rank. To be useful in industry, these parameters have been well correlated to the ASTM stability factor which is a universally accepted property relating to the utilization of coke. Rarely, however, do the optimum amounts of inert macerals exist in coals as they occur in nature. Therefore, selective processing is required to effectively separate and blend the ideal mixtures.

The objective of this study is to define more precisely, by using petrographic and conventional methods of analysis, coke properties and coke-making potential of certain Alaskan coals and blends. Discussions of the interrelations between petrographic data and the physical and chemical characteristics of coals and cokes are presented in conjunction with data describing Alaskan coals representative for different geographic localities.

Coal Macerals

The significance of quantitizing various coal substances by reflected light techniques may be understood by a brief inspection of their physical and carbonization properties. (Systems of petrographic classifications, nomenclature, and properties are given in reference 12). The macerals of each of the respective maceral groups, vitrinite, exinite, and inertinite have similar properties and, therefore, the technological properties are best summarized by discussing these three main maceral groups, the more general classifications in coal petrography. Some elaboration of the vitrinite maceral's within the vitrinite maceral group is required to understand this maceral's importance in the coking process.

In many coals where the occurrence of vitrinite is relatively frequent, it occurs in thick bands and is readily acquired in fairly pure form; thus, more properties of this maceral are defined. However, the macerals of exinite and inertinite are finely disseminated and it is difficult to ascertain their individual properties. The most obvious differences in the macerals are their color (in thin section), percentage of reflection (polished specimens), specific gravity, hardness and/or friability,, structure, and mode of occurrence.

Vitrinite is usually the dominant substance of most coals. It is readily distinguishable as the red matter in thin section and megascopically by the bright banding commonly seen in coal. It is the major coke forming material which, if its rank is within precise limits, exhibits a characteristic plasticity during the carbonization process. These limits are best defined by the percent reflectance with a lower value of approximately 0.8% and an upper limit of approximately 1.5%. Because petrographic rank is given in terms of the vitrinite reflectance, the coking ability is readily predicted.

The density of vitrinite varies with rank from 1.30 (80% carbon) to 1.70 (96% carbon). The distribution of vitrinite in most crushed coal is generally found to increase from 6 mesh to 48 mesh and to decrease from 48 to 150 mesh.

The exinite maceral group, containing the exinoids and resinoids, is readily distinguishable in transmitted light by oval, lenticular shapes, and serrated edges of orange, red, and bright yellow structures. The exinites are very fluid in the coking process, losing all their original structure, and their thermal behavior has a relatively fixed relation to that of vitrinite. Exinite concentration remains fairly consistent throughout the size range from 6 mesh to 150 mesh. Harrison[9] shows a slight decrease from 10 mesh to 35 mesh and an increase from 35 mesh to 150 mesh. Exinite varies in density from 1.16 to 1.70 with corresponding rank of 80% to 96% ultimate carbon.

The inertinite maceral group contains the macerals micrinite, semi-fusinite, sclerotinite, and fusinite. Due to their similar chemical properties, these macerals are similar in physical appearance and physical properties. The volatile matter is generally low and the fixed carbon is high compared to the reactive macerals. They may be considered the "aggregate" which is bound together by the vitrinite "cement" during carbonization. Differentiation of these macerals within the inertinite maceral group has often proved difficult and in some cases impossible. There are essentially no characteristic differences in physical or chemical properties. Semi-fusinite may be considered a transitional maceral between vitrinite and fusinite, possessing intermediate composition and structural features. When studied by reflected light methods, semi-fusinite is arbitrarily separated into one third reactive and two thirds inerts, a convention adopted by many coal petrographers until the properties can be further delineated. Mineral matter in coal is found predominately in these macerals.

Fusinite is uncommon in many coals and its occurrence in any one coal is usually no greater than 5% by volume. Its composition is similar to charcoal with a high percentage of fixed carbon and varying percentages of mineral matter. Fusinite often exhibits and oval structure, having many small vesicles which are frequently mineralized. Due to the high carbon content and low volatile matter, fusinite is sometimes used in coking blends as an additive inert. The inertinites decline in percentage from 6 mesh to a minimum in the 20 or 35 mesh range and then reach a maximum in the minus 150 mesh size.

PREVIOUS INVESTIGATIONS

Petrographic analyses contribute several factors by which a better understanding of coal character and product characteristics may be evaluated and predicted. The analyses yield the maceral percentages which, when their properties are known, determine the composite properties of the coal, and may be utilized to calculate strength and inert indices defining the coke stability factor. This is one of the most important applications of petrographic data. The structural interrelationships and size of the petrographic entities may be rapidly assessed, thus indicating size ranges for liberation. The petrographic rank (average reflectance percent of vitrinite) states precisely the degree of coalification in terms applicable to develop correlations predicting other thermal behavior of coal.

The first significant correlation predicting coke strength on the basis of petrographic data was accomplished by Ammosov.[8] The curves developed by Ammosov related petrographic data from industrial cokes to results from tumbler tests made on the same cokes. The petrographic data was plotted in terms of vitrinite reflectance classes versus the reactive and inert ratios for optimum coke character. A similar set of curves has been developed by Schapiro and Gray.[17] From these existing relationships, it is possible to "petrographically" calculate the coke stability factor. By plotting a composition-balance index and the strength index on Figure 1, the coke stability factor may be determined. If a coal blend is composed of different coals with several different vitrinite types, the coke stability may be evaluated similarly. Detailed demonstration of these calculations are found in reference number 8.

Previous researchers (references 16, 17, and 18) have correlated volatile matter and fixed carbon with petrographic rank from which it is possible to use results from proximate analysis to estimate per cent reflectance and thus approximate coking ability. Correlations between grindability and reflectance, fluidity and reflectance, and inert percentages to coke stability have been made and provide useful data to predict properties for coal and coke evaluations.

Although several studies by the aforementioned agencies are concerned with economics, occurrence, reserves, analysis for classification and steam generation, and washability tests, few reports concerning carbonization tests on Alaskan coals are available. Two references containing data pertaining to coking characteristics of certain Alaskan coals were located.

The results of sixty-seven low temperature carbonization assays are reported in U. S. Bureau of Mines Bulletin 571.[19] All but one of the samples proved to be char. The single exception was a coke product described as "much swelling, complete fusion, small to large cells, with a bright luster." All but 17 samples were reported as grab samples. The weathered condition of these samples was not reported.

The U. S. Bureau of Mines *Bulletin* 510[7] represents, in part, a study of the carbonizing properties of certain coals from the Matanuska

Valley. The coals used in this study were number 3 bed from the Evan Jones Coal Company, and M bed from the Chickaloon Mine. The results showed that number 3 bed "yielded poorly fused coke or char and M bed ranked as medium volatile bituminous and coked strongly."

INVESTIGATIONS ON ALASKAN COALS

To produce coke, definite ranges of coal ranks are used: low and medium volatile bituminous and high volatile A, B, and C bituminous. The reader is referred to ASTM specifications, "Classifications of Coal by Rank"[1] for the respective limits of fixed carbon, volatile matter, and heating value. Though all of the above mentioned coals are used for coking, only low and medium volatile bituminous coals are capable of being coked without blending. The lower rank coals may be blended with the low medium volatile ranks to produce a coke.

The coking process is initiated by successive softening, swelling and devolatilization, and resolidification into a coherent mass. There are three general requirements for the coking process: (1) The coal must have a composition balance within certain limits. This composition may be expressed in terms of proximate and/or ultimate analyses or better, in terms of petrographic rank and composition. (2) The coal charge must have homogeneous distribution of its constituents which is controlled by the kind and degree of pulverization. According to recent reports by Wolfson,[21] Harrison,[9] and Brisse,[3] top size of coal charge consists vary from 12% to 60% retained on a ⅛" sieve. Burstlein,[5] Marshall, et al.[15], indicate that a bimodal size distribution is best for coking charges. The consist should be weighted high in the coarse size, ⅛" to 28 mesh (Tyler), and high in the finer sizes, 48 to 65 to 150 mesh, with low proportions in the intermediate size range. (3) The carbonizing process itself must be controlled so that the charging temperature, temperatures of the fluid range, and rate of heating are properly controlled. Also, bulk densities and moisture content must be maintained within certain limits.

Of these three general requirements, the composition of the coal in terms of proximate analysis and petrographic data is the main concern of this study.

Nine representative coal samples were collected from four different localities in Alaska for examination by reflected light methods to predict their coking ability. These same coals were analyzed by proximate analysis for free-swelling indices, Hardgrove grindability indices, and sizing and specific gravity separation characteristics. Micro-oven coke and tumbler tests were performed on single coals and blends of these coals. The experimentally determined coke strengths were compared to those predicted by petrographic methods.

Reflected Light Studies

The following coals were selected for examination by reflected light techniques: Lower Castle Mountain seams 5, 8, 7U and 7L, from Evan Jones Coal Company; 3 seam Eska from Moose Creek; and seams 2 and 3 from Usibelli Coal Mine, Healy, Alaska. Approximately 100 pounds of each coal was collected in air tight containers and are representative of the total seam section with the exception of 8 seam in which only the bottom half of the seam (4 feet) was sampled.

Representative samples of these nine coals were sent to Dr. H. R.

Brown and Associates, Coal Research Division, C.S.I.R.O., Australia, for detailed petrographic analyses,[6] Five different processed coal products of 5, LCM, UCM, 3 Eska, and 3U seams were contracted to John A. Harrison, Illinois Geological Survey, for petrographic analyses. These products are representative of the 1.30 specific gravity float fraction of the 3 x 8 mesh size fraction. This size fraction represents the coarsest size to which the seams were crushed. The samples were selected from this coarser size to indicate minimum liberation of macerals and ash percentages. The low specific gravity was chosen for the purpose of obtaining high concentrations of the reactive macerals. The following data represent petrographic analysis for determination of rank (mean maximum reflectance value of vitrinite) and maceral analysis. Table 1 gives the petrographic maceral data for the nine representative coals, and Table 2 lists the data for five specific gravity products.

Petrographic Prediction of Coke Stability

Using the available petrographic data, it is possible to calculate the inert and strength indices necessary to define the coke stability. Calculations of coke stability of ROM (−3 mesh), sink-float products, and blends of sink-float products were made using established curves of Harrison[11] and Schapiro[17], and are illustrated in Figure 1. The darkened circles denote the ROM products, the dotted circles denote the float products, and the triangles represent approximate interpolated stability values for the blends which are further discussed in the Coke Testing section.

Acceptable stability for blast furnace and foundry use ranges from approximately 40 to 65. Inspection of the predicted stabilities for the Alaska coals indicate that they are of inferior quality for use as a metallurgical coke. Possible exceptions to this are LCM and UCM seams which have calculated stabilities of approximately 30 and 65 respectively. LCM bed is synonymous with M bed as reported in U. S. Bureau of Mines Bulletin 510.[7] From analysis of the isostability curves, it can be observed that strength index is dependent mostly on vitrinite type percentages, rank, and to a lesser degree on the percentages of exinoids and resinoids. This is generally the case for most coals, but is more pronounced for Alaskan coals where the percentage of the exinoids and resinoids are low, especially in comparison to vitrinite percentages.

A horizontal fluctuation on the graph is a function of the ratio of reactives to inerts, their absolute values, and to a lesser degree the types of vitrinite present. In order to increase the stability of LCM, the point on the graph would have to be moved to the left a considerable amount. For example, to attain a predicted stability of about 45, the inert index would have to be roughly 1.3 which would require that approximately 28% inerts must be added to the coal charge. This addition of inerts would lower the percentage of reactives but would increase the strength index slightly from 3.4 to 3.5. Therefore, it is theoretically possible to improve the stability of LCM from 30 to 45 by adding 28% inerts. Thermal metamorphism, indicated by a wide vitrinite type spread, has oxidized UCM seam below the critical oxidation level required for coking. Coking of this coal substantiates petrographic interpretation.

TABLE I

Maceral Compositions of Nine Alaskan Coals*

		MACERALS (%)						
		REACTIVES			INERTS			
Seam	Location	Vitrinite	Exinite	Resinite	Micrinite	Semifusinite	Fusinite	Mineral Matter
2U	Usibelli Coal Mine, Healy	62	11	4	2	5	—	16
3U	Usibelli Coal Mine, Healy	74	14	7	1	2	—	2
5	Evan Jones Coal Mine, Sutton	68	6	1	1	—	—	24
7U	Evan Jones Coal Mine, Sutton	77	3	2	—	1	—	17
7L	Evan Jones Coal Mine, Sutton	66	3	6	2	1	—	22
8	Evan Jones Coal Mine, Sutton	73	6	—	—	—	—	21
3 Eska	Moose Creek	85	3	5	2	1	—	4
LCM	Chickaloon	90	2	—	1	—	—	7
UCM	Chickaloon	89	—	—	—	2	—	9

*Maceral analyses conducted by Coal Research Division, C.S.I.R.O., Australia.[6]

TABLE 2

Maceral Composition of 3 x 8 Mesh Fractions Floated at 1.30 Specific Gravity*

	MACERALS (%)								
	REACTIVE MACERALS					INERT MACERALS			
Seam	Vitrinite[1] Banded	Vitrinite[1] Attrital	Vitrinite[1] Total	Exinite	Resinite	Semifusinite	Fusinite	Micrinite	Mineral Matter
5	41.28	47.33	88.61	0.83	7.06	0.83	0.17	1.25	1.25
LCM	58.59	37.58	96.37	0.55	0.88	0	0.44	1.21	0.55
UCM	60.22	28.27	88.49	1.39	1.77	0.51	1.52	3.79	2.53
3 Eska	28.64	58.06	86.70	10.37	1.01	0.90	0	1.02	0
3U	11.12	55.51	66.63	24.60	2.34	0.58	0.82	4.22	0.81

[1]Vitrinite is divided into banded and attrital. Attrital vitrinite refers to that vitrinite which is initimately mixed with other macerals and in which the vitrinite-other macreal ratio is less than 1:3.

*Analyses by John A. Harrison, Illinois Geological Survey.

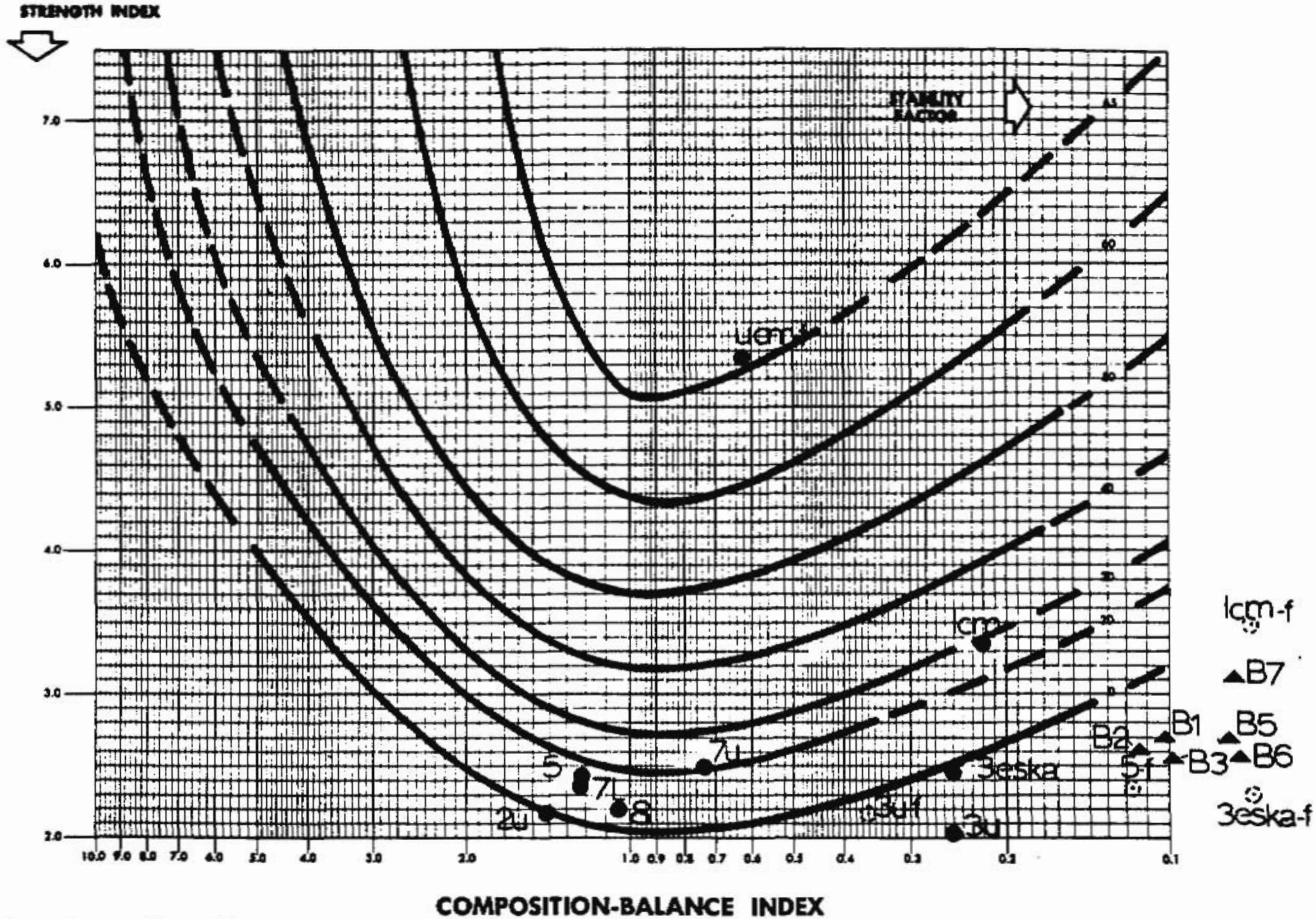

Fig. 1. Correlation chart illustrating petrographically calculated coke stabilities of ROM, float products, and blends of Alaskan coals. (Chart from Bituminous Coal Research, Inc., 1964)

An important point to consider is the fact that the mineral matter is very high in the ROM samples. Inspection of Table 1 indicates that the coals are rich in vitrinite and in most cases extremely so if mineral matter is not considered. All predictions as plotted on Figure 1 considered the percent mineral matter. However, knowing that the maximum allowable percent of ash in coke is approximately ten percent, the coal must be processed to eliminate much mineral matter. A reasonable percentage of mineral matter to be removed would be 60%. In the case of LCM, if 60% of the mineral matter were removed, the percentage of vitrinite would increase from 90% to 94.2% which would in turn lower the inert index to about 0.13 and increase the strength index slightly. However, the overall result would be a lowering of the stability from 30 to 20. This has happened to all the sink-float products as evidenced by their calculated stabilities.

Conventional Analysis

All nine coals as used for petrographic examination were stage crushed to minus 3 mesh (Tyler). Analyses as indicated in Table 3 were performed on ROM samples.

Proximate analysis is the most common test performed on coal and cokes. Results from the volatile matter test and the cake button derived therefrom yield the volatile matter percentages which classify the coals according to ASTM rank, indicating the probable quantitative yield of coke, and the quantity of volatiles and liquid by-products to be expected from coking the coal. Visual observation of the cake button produced from the volatile matter test is also a measure of the coherence and swelling properties.

Hardgrove grindability data was first used as an indication of the relative strength requirements for size reduction. The grindability index has recently been used as a supplemental rank indicator and as an indicator for the change in the reactive-inert ratios during processing. Grindability values between 60 and 90 are usually indicative of low and medium volatile bituminous coals. According to Wolfson, et. al.[22] free-swelling indices of blast furnace coke blends generally range from 5.5 to 8.0.

Coke Testing

Since only limited quantities of proven coking coals are presently known to exist in Alaska, emphasis has been directed toward the blending of large quantities of non-coking coals with smaller amounts of coking coals to obtain blends capable of being coked.

After perusal of the literature, and in view of the time and facilities available, certain arbitrary conditions and standards had to be established for conducting the tests. These "standards" were based on comparison to other similar coals in which carbonization tests had been performed. Illinois numbers 5 and 6 seams are two such coals which have been studied by carbonization. The petrographic rank of Illinois number 6 seam is given as 0.70% by Harrison[33] and, according to the

TABLE 3

Conventional Analyses of Nine Representative Alaskan Coals

Seam	Location	PROXIMATE ANALYSIS (%) Condition*	Moisture	Ash	Volatile Matter	Fixed Carbon	Hardgrove Grindability Index	Free-swelling Index
5	Evan Jones Coal Co.	1	3.84	23.72	33.77	38.67	52.4	1.5
		2		25.30	36.02	38.68		
		3			48.21	51.78		
8	Evan Jones Coal Co.	1	5.99	23.24	32.90	37.87	48.8	1.5
		2		25.08	35.50	39.42		
		3			47.38	52.61		
7U	Evan Jones Coal Co.	1	—	—	—	—	52.2	1.5
		2		21.71	36.00	42.29		
		3			45.98	54.01		
7L	Evan Jones Coal Co.	1	—	—	—	—	52.7	1.5
		2		21.31	44.56	34.13		
		3			56.68	43.37		
3 Eska	Moose Creek	1	4.45	9.31	38.66	47.58	50.7	1.5
		2		9.86	40.96	49.18		
		3			45.44	54.55		
LCM	Chickaloon	1	3.10	12.60	28.17	56.13	77.7	6.5
		2		13.00	29.07	57.93		
		3			33.41	66.59		

TABLE 3—(Continued)

Conventional Analyses of Nine Representative Alaskan Coals

Seam	Location	PROXIMATE ANALYSIS (%)					Hardgrove Grindability Index	Free-swelling Index
		Condition*	Moisture	Ash	Volatile Matter	Fixed Carbon		
UCM	Chickaloon	1	4.86	18.63	17.46	59.05	72.5	0
		2		19.78	18.54	61.68		
		3			23.11	76.88		
3U	Usibelli	1	—	—	—	—	28.6	0
	Coal Co.	2	—	7.16	53.67	39.17		
		3	—		57.80	42.19		
2U	Usibelli	1	19.29	14.21	47.86	18.64	34.9	0
	Coal Co.	2		20.57	69.25	10.18		
		3			87.18	12.82		

*Condition: 1 As rec'd basis; 2 dry basis; 3 moisture and ash-free basis (daf)

TABLE 4
Tumbler Test
Results of Single Coals

Test	Sample	Run	Coke Yield (%)	Cumulative Wt % Retained on		
				1" (Stability)	¼"	½" (Hardness)
1.	Taggart	1	64.0	0	79.7	79.7
		2	67.0	0	86.5	86.5
		3	66.0	0	86.4	86.4
		Average	65.7		84.2	84.2
2.	Imboden	1	68.0		85.3	85.3
		2	69.0	0	84.1	87.0
		3	66.0	0	80.3	81.8
		Average	67.7		83.2	84.7
3.	LCM (ROM)	1	71.0	45.0	69.4	70.9
		2	72.0	27.8	73.6	75.0
		3	71.0	11.3	76.1	76.1
		4	72.0	0	73.2	78.9
		Average	71.5	20.7	73.1	75.2
4.	LCM (3 x 8, 1.30 Float)	1	69.0	34.8	60.9	66.6
		2	70.0	16.7	69.7	69.7
		Average	69.5	25.6	65.6	68.2
5.	LCM (3 x 8, 1.30-1.40F)	1	72.0	62.5	76.4	76.4
		2	71.6	16.6	72.6	73.5
		Average	71.8	39.5	74.5	74.9

TABLE 4

(Continued)

Blend	Sample	Run	Coke Yield (%)	Cumulative Wt % Retained on 1" (Stability)	½"	¼" (Hardness)
6.	LCM 3 x 8, 1.40-1.50F)	1	75.0	82.6	82.6	82.6
		2	74.6	84.1	84.1	84.1
		Average	74.8	83.4	83.4	83.4
7.	5 (ROM)	1	60.0	0	0	0
8.	3 Eska (ROM)	1	67.9	0	0	0
9.	5 Seam 3 x 8, 1.30 Float	1	68.0	0	82.8	84.9
10.	UCM (ROM)	1	No Coke Product			
11.	3 Usibelli	1	No Coke Product			
B7	70% LCM (3 x 8, 1.30F)	1	65.2	0	82.9	83.4
	30% 5 (3 x 8, 1.30F)	2	65.7	0	75.5	75.9
		Average	65.4	0	85.7	85.8
B8	80% LCM (3 x 8, 1.30F)	1				
	30% 5 (48 x 100, 1.30F)					
B9	70% 5 Seam (14 x 28)		67.9	25.9	34.8	39.0
	30% LCM (14 x 28)	2	68.2	24.2	30.1	34.1
		Average	68.0	25.1	32.5	36.6

TABLE 5
Tumbler Test
Results of Blends

Blend	Sample	Run	Coke Yield (%)	Cumulative Wt % Retained on		
				1" (Stability)	½"	¼" (Hardness)
B1	70% 5 (3 x 8, 1.30F)	1	65.5	0	83.8	83.8
	30% LCM (3 x 8, 1.30F)	2	63.8	0	78.4	83.5
		3	63.3	0	78.7	81.5
		Average	64.2		80.3	82.9
B2	80% 5 (3 x 8, 1.30F)	1	61.5	0	81.3	81.3
	20% LCM (3 x 8, 1.30F)	2	61.6	0	78.6	81.2
		Average	61.6		80.0	81.3
B3	40% 3 Eska (3 x 8, 1.30F)	1	60.6	0	82.5	82.5
	40% 5 (3 x 8, 1.30F)	2	61.3	0	82.5	82.8
	20% LCM (3 x 8, 1.30F)	Average	61.0	0	82.5	82.7
B4	70% 5 (3 x 8, 1.30F)	1	64.2	0	67.9	71.8
	15% LCM (3 x 8, 1.30F)	2	63.2	0	72.6	73.3
	15% UCM (3 x 8, 1.30F)	Average	63.7	0	70.3	72.6
B5	70% 3 Eska (3 x 8, 1.30F)	1	60.4	0	84.1	87.7
	30% LCM (3 x 8, 1.30F)	2	61.0	0	82.5	87.0
		Average	60.7		83.3	87.4
B6	80% 3 Eska (3 x 8, 1.30F)	1	60.0	0	77.7	77.7
	20% LCM (3 x 8, 1.30F)	2	60.0	0	70.8	73.7
		Average	60.0		74.3	75.7

TABLE 6
Tabulated Data of Petrographic Parameters and Tumbler Test Results

Sample	PETROGRAPHICALLY CALCULATED PARAMETERS					EXPERIMENTAL LAB TESTS		
	% Inerts in Coal	% Inert for Optimum Coke	Inert Index	Strength Index	Stability Factor	Tumbler Lab Tests 1"	½"	¼"
All ROM Samples								
LCM	8.0	35.9	0.22	3.37	28	22	73	75
3 Eska	6.7	26.8	0.25	2.47	0	0	0	0
7U	17.7	24.1	0.73	2.49	20		NA	
7L	24.7	20.3	1.22	2.37	10		NA	
8	21.0	20.2	1.05	2.22	8		NA	
5	25.0	20.7	1.21	2.41	12	0	0	0
2U	21.4	14.1	1.51	2.18	0	0	0	0
3U	4.4	16.6	0.26	2.03	0	0	0	0
UCM	8.4	13.5	0.62	5.34	60	0	0	0
All 3 x 8, 1.30 Float Samples								
LCM	2.2	34.1	0.06	3.50	5	25.6	65.3	68.2
3 Eska	1.6	27.4	0.06	2.31	0	0	0	0
5	3.2	27.7	0.12	2.34	0	0	82.8	84.9
3U	6.2	17.4	0.36	2.18	0	0	0	0
UCM	8.3	13.5	0.62	5.34	65	0	0	0
Blends								
B1	3.1	30.2	0.10	2.70	0	0	80.3	82.9
B2	3.2	28.9	0.11	2.57	0	0	80.0	81.3
B3	2.6	28.8	0.09	2.56	0	0	82.5	82.7
B5	2.0	29.9	0.07	2.68	0	0	83.3	87.4
B6	1.9	28.7	0.07	2.55	0	0	74.3	75.7
B7	2.1	32.1	0.07	3.11	0	0	79.2	79.7

report the inert and strength indices of this seam approximate those of the high volatile bituminous coals of Evan Jones Coal Company. Therefore, the following coking conditions were established as standard for all samples coked:

Charging temperature 475°C
Rate of temperature 3.5°C/min.
Final coking temperature 1000°C
Final coking period 1½ hours

The rate of temperature increase was not constant throughout the heating cycle from 475°C to 1000°C due to lack of furnace control. The recorded heating rate was somewhat higher between 475° and 750° (approximately 5°C/min. and then tapered to a slower rate (approximately 2-3°C/min.) between 750° and 1000°C. The average rate for the process was 3.5°C/min. for a 2½ hour period.

Twenty-five percent retained on 8 mesh was selected as top size for all charges except where otherwise indicated. All coal charges, 100 grams in weight, were placed in Dixon graphite crucibles of the bowl shaped type and covered with graphite lids. The coals were coked under the standard conditions and the resultant coke quenched by dipping in a pail of water for approximately five seconds. The cokes were allowed to dry for one day at room temperature to insure complete evaporization of water to prevent any possible discrepancies in the tumbler test results.

The tumbler test apparatus consisted of a modified stainless steel drum resembling the ASTM tumbler apparatus.

The sieves used to determine the degradation characteristics were 1", ½", and ¼". It was doubtful at first that reproducibility could be achieved by tumbling only 65 to 70 grams of coke. To check the reproducibility, several identical coals were coked and tumbled. Triplicate samples of two eastern U.S. coals, Taggart and Imboden seams, and four tests on LCM (all reported to yield a coherent coke product) were coked under standard conditions with results tabulated in Table 4. From these results, it can be said that reproducibility is not excellent but that the values do indicate relative coke strengths. The results of tumbler tests for all cokes and blends are given in Tables 4 and 5.

The results of coking various specific gravity fractions of LCM indicate increasing strength with increasing specific gravity. It is important to note that the strength of these products is significantly stronger than the ROM seam. All the blends have similar coking characteristics except for the B9 blend in which the charge consist was 14 x 28 mesh. The stability is high in comparison to the other blends; however, the hardness index is very low. Relatively few fines were created by most cokes. It is significant to note that the tumbler results of all blends are comparable to those exhibited by commercial chemical coke blends. The petrographically calculated coke properties are compared with the experimentally determined coke properties in Table 6.

Plates 1 through 7 illustrate results of coking and tumbler tests as follows:

PLATE 1 – A, B, and C illustrate the coke obtained from ROM seams UCM, LCM, and 5 seam respectively. UCM seam did not coke. LCM coked fairly well, and 5 seam produced a fine grained highly fractured char. The three small coke products immediately beneath A, B, and C are blends of those three seams. D, E, and F represent the coke products of three specific gravity fractions of LCM. D represents the 1.30 float product and is much expanded showing vertical fractures. E is the 1.30-1.40 float fraction and illustrates a lesser degree of expansion. F is the 1.40-1.50 float product and exhibits a slight contraction. The experimental stability factors are approximately 25, 40, and 83 for D, E, and F respectively. Free-swelling indices of these three products are 9, 8, and 5 respectively. It is apparent that the distribution of reactive and inert entities greatly affect the strength, contraction-expansion, and the free-swelling indices. G, H, and I represent the same specific gravity fractions of 5 seam. G illustrates the effect of a high concentration of low vitrinite types resulting in a fine granular char. In H a better balance in the composition is exhibited by a more uniform texture and increased porosity. I represents a product too rich in inerts yielding a poorly fused, coarse textured product.

PLATE 2 – Imboden coke, illustrated in E, is reported[7] to have a stability factor of 40. However, the sample used may not have this stability. In any case, an eastern U. S. coking coal is available for comparison. A and C represent the cokes of LCM and 5 seams (all 3 x 8, 1.39 float) from which B, blend B1, was obtained. D illustrates tumbler test results of Imboden coke. The products in D and E have similar texture and porosity. The calculated stability for blend B1 is zero but the percentage retained on the ½" and ¼" sieve is 80 and 83 respectively, indicating a high hardness factor.

PLATE 3 – A and C illustrate the 1.30-1.40 float product of LCM and the 1.30 float product of 5 seam respectively. The resultant blend (70% LCM and 30% 5 seam) produced a strong coherent coke and exhibited a decrease in expansion in comparison to blend B1, Plate 2. D and F represent the 1.30-1.40 float product of LCM and 5 seams respectively. The resulting blend (70% LCM and 30% 5 seam) produced the coke in E which exhibited a stronger coke than in B, which was expected since by decreasing the specific gravity, the percentage of inerts approached the optimum ratio. G shows blend B5 which resulted in a mottled, poorly fused, coarse texture.

PLATE 4 – A represents the coke of UCM (ROM) and B the coked 5 seam (ROM). C and D represent the cokes of 8 x 14 and 14 x 28 size fractions of 3 Eska respectively. Neither sample produced a coherent coke, but it is evident that different sizes produce contrasting coke characteristics. E illustrates blend B9 of the 14 x 28 size consist of LCM and 5 seam. F is the resulting tumbler test product of blend B9, having an observed stability of 25 as compared to a stability of zero with the same coals using a wider range of sizes. The hardness of blend B9 is significantly lower than the blend having a wider size range.

PLATE 5 – A shows the coke of UCM (ROM) and may be compared to blend B4 in B which is a combination of UCM, LCM, and 5 seam. C represents the same blend of coals but uses the 14 x 28 size consist rather than the 3 x 8, 1.30 float material. The latter blend yielded a more uniformly textured product. D shows the tumbler test results of the blend in C. E and F are the coke and tumbler results of blend B3 respectively which yielded a calculated and experimental stability of zero, but which had a high hardness factor of 82.

PLATE 6 – A illustrates blend B2 and B shows the tumbler results of this blend. It is noted that by decreasing the percentage of coking coal in the blend from 30% to 20%, the ½" and ¼" sieve indices were significantly lowered by 10 points. C represents coke produced from the 14 x 28 size fraction of LCM. When comparison of this product is made to the picture of LCM coke product of a wide size range as in B, Plate 1, it is evident that the coking ability is sreiously decreased when a single size consist is used.

PLATE 7 – A and B show cross-sections of the cokes produced from LCM (ROM) and a blend of 30% LCM and 70% 5 seams (all 1.30-1.40 float material) respectively. Large porous structures and fissuring are evidenced in picture A, while the blend has a coherent uniform structure. These products illustrate the porosity characteristics and coherence as affected by variations in the petrographic composition. C and D are tumbler results of blend B5 and the 1.30 float fraction of 5 seam. They may be easily compared to pictures E and F which illustrate the tumbler results of Taggart and Imboden seams respectively.

PLATE 1

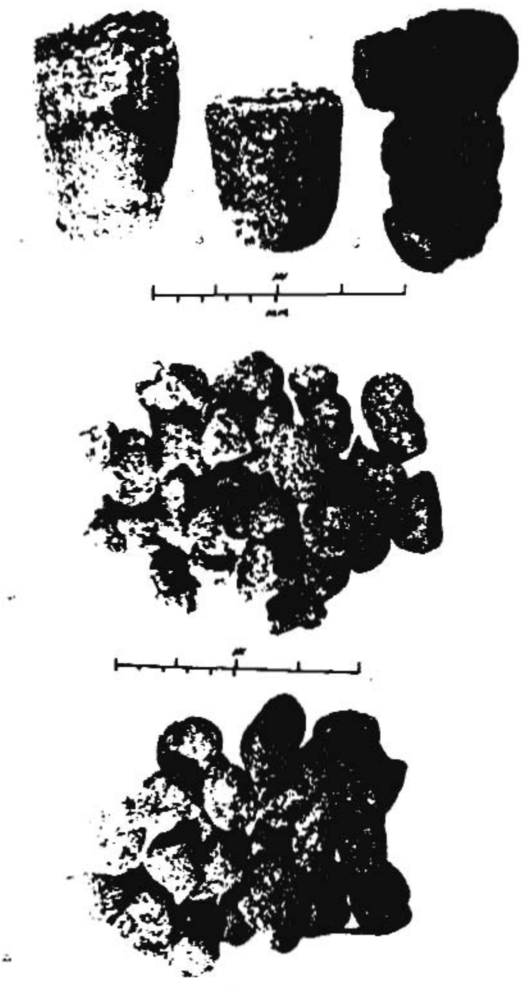

PLATE 2

PLATE 3

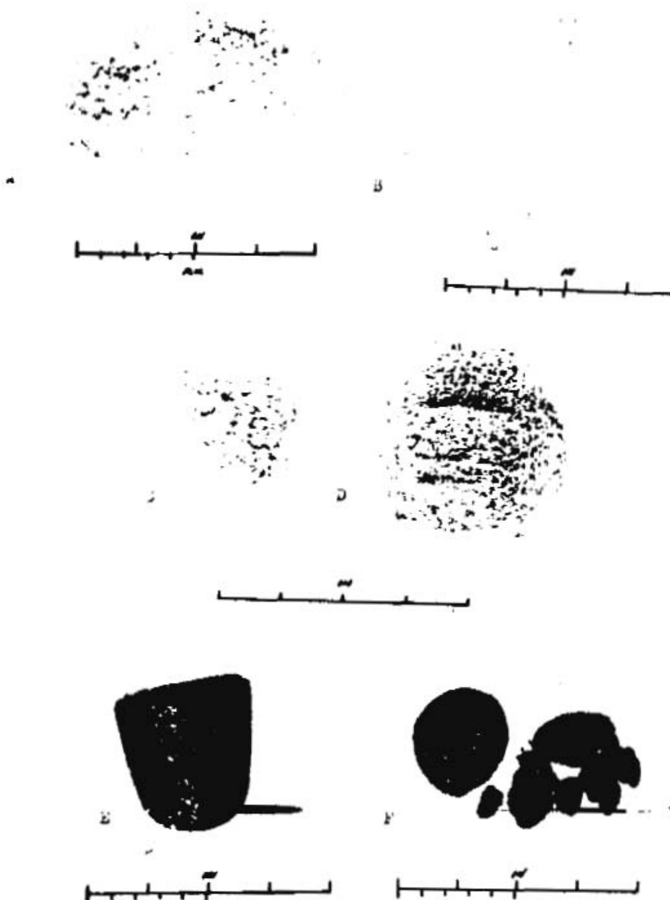

PLATE 4

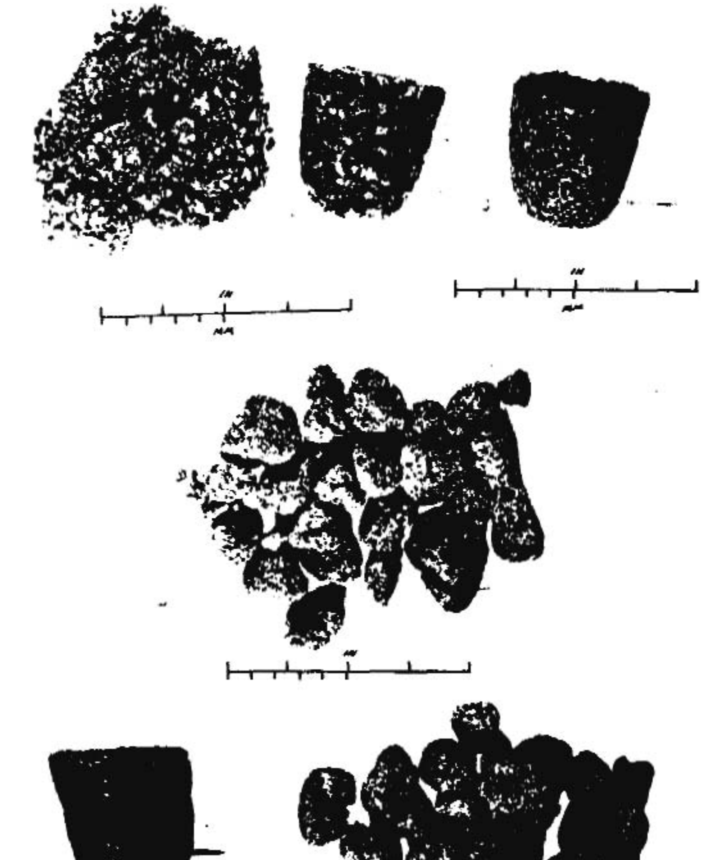

PLATE 5

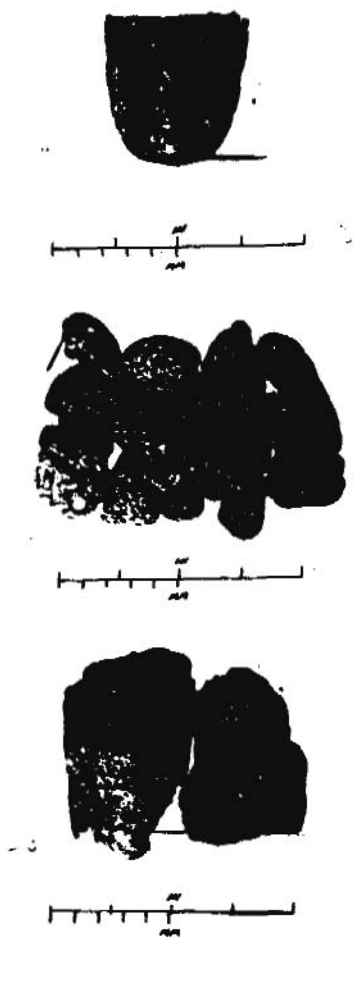

PLATE 6

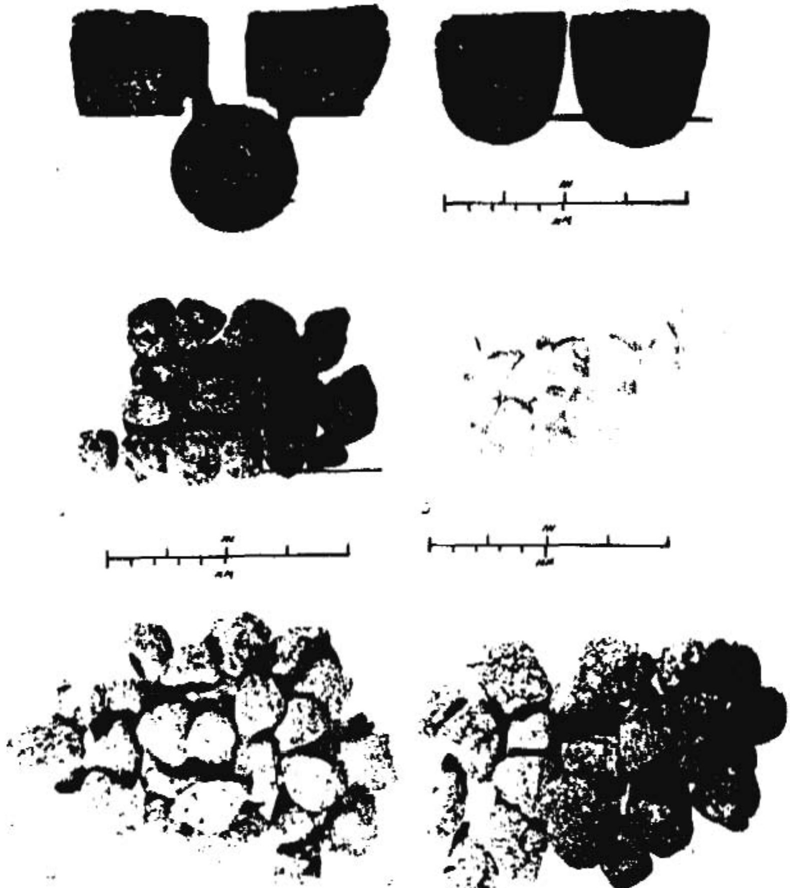

PLATE 7

SUMMMARY AND CONCLUSIONS

Petrographic examination has yielded much information concerning the preparation and coking of certain Alaskan coals. Based on petrographic analyses, sizing, sink-float tests, and micro-oven coke tests, methods are indicated for processing the Lower Castle Mountain coal to yield a metallurgical coke. The composite data have also been used to indicate the strength characteristics of certain Alaskan coals and blends, to express the characteristics of acceptable coal mixtures and to stress the importance of uniformity of both composition and structure in blended coals.

From tabulated maceral analyses and predicted coke stabilities, several facts are evident: The inert percentages for all coals and blends tested are below those required for optimum coking conditions. The plotted stabilities indicate that all coals under study have inferior qualities for use as metallurgical coke with the possible exception of LCM seam. However, by using higher specific gravities, approximately 1.45, and lower pulverization levels, 10% +⅛", for processing, coke with stabilities from 20 to 35 may be produced by blending LCM seam with high volatile bituminous coals. Maceral distribution is greatly affected by sink-float separations. All coals from the Matanuska Valley are extremely rich in vitrinite and low in inertinite macerals. Agreement of petrographic maceral analyses from two different sources is good. Free-swelling indices of ROM coals indicate coking quality with the exception of LCM.

Coke tests were conducted on ROM samples, sink-float products, and blends of sink-float products. Results of coke tests have been given in terms of coke yield and cumulative percentages retained on 1", ½", and ¼" sieves. Petrographically predicted coke stabilities are given and agree fairly well with experimental tests. Indicative of the validity of the experimental tests is fair agreement between the calculated stability of LCM, 28, and the value 22 determined from the tumbler test. The hardness factor is high (75) and comparable to those values attained by many eastern U. S. coking coals. Inert percentages of this seam are very low and especially so when mineral matter is not considered. However, it is possible to process the coal at lower specific gravities to obtain inert indices of 0.8 or 0.9 which would increase the coke stability to 45.

It has been illustrated that coherent coke products may be made by blending LCM coal with non-coking high volatile bituminous seams of the Matanuska Valley. Although most of these cokes have zero stability, as determined by the modified tumbler test and calculated petrographically, they do exhibit high ½" and ¼" hardness indices. These indices are similar for all blends, varying from 65 to 85, and are comparable to the indices of chemical cokes presently produced from Illinois coals of similar rank.

RECOMMENDATIONS

The following are recommendations for future coal investigation programs:

1. Proximate and ultimate analyses to precisely define the character of cokes produced in this investigation.
2. Carbonization studies on these same coals but which have been processed to smaller sizes and separated at higher specific gravities.
3. Geiseler fluidity tests to determine plasticity and heating conditions required for coking specific Alaskan coals.
4. Carbonization studies to define useful by-products which can be produced from Alaskan coals.
5. Comprehensive petrographic analyses on Alaskan coals worthy of economic exploitation.
6. Determination of the specific gravities yielding the optimum inert and strength indices for specific coals.

BIBLIOGRAPHY

1. American Society for Testing and Materials, ASTM STANDARDS ON COAL AND COKE, 14th Edition, December, 1962.

2. Ammosov, I. L., and others, CALCULATION OF COKING CHARGES ON THE BASIS OF PETROGRAPHIC CHARACTERISTICS OF COALS, Koks I. Khimiyn, 12: 9-12, 1957.

3. Brisse,, A. H., Harris, H. E., SOME BASIC PRINCIPLES OF PULVERIZATION AND PREPARATION OF COKING COAL BLENDS, Blast Furnace and Steel Plant, March, 1957.

4. Brown, H. R., Taylor, G. H., and Cook, A. C., PREDICTION OF COKE STRENGTH FROM RANK AND PETROGRAPHIC COMPOSITION OF AUSTRALIAN COALS, Fuel, Vol. XLIII, No. 1, January, 1964.

5. Burstlein, E., LA PREPARATION PETROGRAPHIGUE DES CHARBONS ET SON APPLICATION A L'INDUSTRIC DE LA DISTILLATION DE LA HONILLE, Association •Technique de l'Industrie du Gas en France, 1950.

6. Commonwealth Scientific and Industrial Research Organization, PETROGRAPHIC EXAMINATION OF NINE ALASKAN COALS, Unpublished, Miscellaneous Report No. 269.

7. Davis, J. D. et al, CARBONIZING PROPERTIES: BRITISH COLUMBIA, MATANUSKA VALLEY (ALASKA), AND WASHINGTON COALS AND BLENDS OF SIX OF THEM WITH LOWER SUNNYSIDE (UTAH) COALS, U. S. Bureau of Mines Bulletin 510, 1952.

8. Hankinson, F. C., PETROGRAPHY AS RELATED TO SELECTION, PREPARATION, AND COKING OF CERTAIN ALASKAN COALS, Master's Thesis, Unpublished, University of Alaska, College, Alaska, May, 1965.

9. Harrison, J. A., APPLICATION OF COAL PETROGRAPHY TO COAL PREPARATION, Transactions of SME, Vol. 226, December, 1963.

10. Harrison, J. A., COAL PETROGRAPHYY APPLIED TO COKING PROBLEMS, Illinois Mining Institute, 69th Year, 1961.

11. Harrison, J. A., PREDICTING COKE STABILITY FROM PETROGRAPHIC ANALYSIS OF ILLINOIS COALS, llinois State Geological Survey, Circular 336, 1964.

12. International Committee of Coal Petrography, INTERNATIONAL HANDBOOK OF COAL PETROGRAPHY, Centre National de la Recherche Scientifique, France, 1963.

13. Jackman, H. W. and Helfinstine, R. J., COKE CRUSHING CHARACTERISTICS, Illinois State Geological Survey, Circular 375, 1964.

14. Leonard, J. W., DETERMINING COKE STABILITY FROM COAL HARDGROVE GRINDABILITY, BULK, DENSITY, PULVERIZATION LEVEL AND VOLATILE MATTER, Coal Research Bureau, Tech. Report No. 8, School of Mines, West Virginia University, West Virginia, 1964.

15. Marshall, C. E. and others, PETROGRAPHIC AND COKING CHARACTERISTICS OF COAL, A LABORATORY STUDY OF ILLINOIS NO. 5 AND NO. 6 COAL BEDS, Illinois Geological Survey Bulletin 84, 1958.

16. Schapiro, N. and Gray, R. J., PETROGRAPHIC CLASSIFICATION APPLICATIONS TO COALS OF ALL RANKS, Proc. of the Ill. Min. Inst., 1960.

17. Schapiro, N. and others, RECENT DEVELOPMENTS IN COAL PETROGRAPHY, blast furnace, coke oven and raw materials, Proc., AIME, Vol. 20, pp. 89-112, 1961.

18. Schapiro, N. and Gray, R. J., THE USE OF COAL PETROGRAPHY IN COKE MAKING, Journal of the Institute of Fuel, June, 1964.

19. Selvig, W. A. and Ode, W. H., LOW-TEMPERATURE CARBONIZATION ASSAYS OF NORTH AMERICAN COALS, U. S. Bureau of Mines Bulletin 571, 1957.

20. Stopes, Marie C., ON THE PETROLOGY OF BANDED BITUMINOUS COAL, Fuel, Vol. 14, 1935.

21. Wolfson, D. E., Birge, G. W., and Walters, J. G., RELATIONS OF PROPERTIES OF COKE PRODUCED BY BM-AGA AND INDUSTRIAL METHODS, Blast Furnace, Coke Oven and Raw Material Proceedings, pp. 387-403, 1961.

22. Wolfson, D. E., Birge, G. W., and Walters, J. G., COMPARISON OF COKE PRODUCED BY BM-AGA AND INDUSTRIAL METHODS, Bureau of Mines RI 6359, 1964.

APPENDIX

DEFINITIONS

Terms used in this report in applying conventional and petrographic data to carbonization evaluations may be defined as follows:

COAL PETROGRAPHY – the systematic and descriptive study of the physical components of coal by microscopic techniques.

EXINITES – a maceral group containing the resinoid and exinoid macerals.

FREE-SWELLING INDEX – measures the swelling properties of a coal, indicates porosity and expansion-contraction phenomena. Free-swelling indices range from 0 to 9. Values from 5 to 8 are generally characteristic of coking coals.

FUSAIN – charcoal like substances. Originates from the same plants as vitrinite but has been subjected to intensive and rapid biochemial alterations resulting in a high degree of carbonization.

HARDGROVE GRINDABILITY INDEX – a measure of the ease with which a coal may be pulverized in comparison with a coal chosen as 100 grindability. The test is based on Rittinger's law, "the work done in pulverization is proportional to the new surface produced."[1]

HARDNESS FACTOR – the percentage of coke sample retained on a quarter inch sieve after subjection to the tumbler test. Indicative of resistance to abrasion.

INERTINITE – a maceral group containing the micrinoids, fusinoids, and semi-fusinoids.

INERT INDEX – the ratio between the percentage of inerts present in the coal and the percentage inerts required to produce optimum coke. Also referred to as the composition-balance-index.

INERTS – coal components whose physical and chemical properties are unchanged or only slightly altered during carbonization.

MACERAL – a microscopic constituent of coal analogous to minerals in a rock.

PETROGRAPHIC RANK – the mean reflectance values of all vitrinite in the coal.

PLASTICITY – measurements which define the temperature at which various physical transformations occur in coal during the heating process. Plastic deformation is largely dependent on coal rank, particle size, homogeneity of constituents, heating and rate and pressure.

POROSITY–dēnotes the size and quantity of pores in the coke structure.

PROXIMATE ANALYSIS – a method for determining the distribution of products obtained by heating coal under standard conditions. Includes the determination of moisture, ash, volatile matter, and fixed carbon and may be reported on three different bases: as received, air-dry, and dry ash-free. Performed according to ASTM procedures.

REACTIVES – coal components that soften and lose their original physical and chemical characteristics during the carbonization process.

REACTIVITY – the rate of carbon dioxide production resulting from the reaction of coke and oxygen. Mainly dependent on coke size, composition, porosity, and reaction temperature.

REFLECTANCE CLASS OR TYPE – denotes a group of reflectance values obtained by measuring the percentage of light reflected from polished coal surfaces. The percentage reflection from vitrinite varies over a wide range depending upon the rank of the coal. Arbitrary reflectance ranges for vitrinite are from 0.1% to 10.0% and are expressed at vitrinite types 1 to 100. Reflectance readings from 0.30 to 0.39 are expressed as vitrinite type V3.

RESINOIDS – macerals consisting of fossilized plant remains. Yellow, orange, or deep red in this section and dark gray in reflected light.

SEMI-FUSINOIDS – macerals which have intermediate composition and structural form between vitrinite and fusain.

STABILITY FACTOR – expresses coke strength. It refers to the percentage of coke samples retained on a one inch sieve after testing by the standard ASTM tumbler procedure. Indicative of the breakage to be expected as the coke descends in the blast furnace.

STRENGTH INDEX – a number on an arbitrary scale from 0 to 7 which expresses the coking strength of coal.

ULTIMATE ANALYSIS – expresses the composition of coal in percentages of carbon, nitrogen, hydrogen, oxygen, sulfur and ash. The carbon includes all of that which is present in organic compounds and in mineral carbonates. Hydrogen and oxygen contents include that present in the organic substances, moisture in the coal, and water of constitution of minerals. Sulfur is present in three forms: organic, pyrite or marcasite, and inorganic sulfates. All nitrogen is present as part of the organic coal substance.

VITRINITES – macerals which are red to dark orange in this section. Are the major coke-making constituents of coal. Exhibit a characteristic plasticity when their reflectance percentages are between 0.8% and 1.5%.